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The Impact of the CTI Correction Pre-Processor Upon Standard STIS CCD Pipeline Dark and Bias Reference Files DRAFT

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1.Introduction

The STIS calibration pipeline is fed with dark and bias reference files which are created from numerous dark exposures and bias readouts. STScI has a comprehensive procedure for obtaining this data and combining it in an optimal way so as to provide the best possible reference files for any given epoch.

Use of the CTI pre-processor (Bristow 2004) with raw CCD data raises some issues when considering how to perform dark and bias correction in the subsequent pipeline calibration. Essentially dark observations themselves suffer from Charge Transfer Inefficiency (CTI) during readout. Therefore they need to be corrected for CTI in the same way as the real data. The dark reference files however are a non-trivial combination of many dark observations, possibly with different exposure times. In order to correct any given reference file we would need to correct multiple dark observations and recombine them.

Moreover, this has a rather subtle knock-on effect for bias reference files that need to be modified for use with raw data that has been CTI corrected.

Firstly we outline the ideal procedure for rederiving dark reference files, not because we propose that this should be done (indeed below we demonstrate that it is not likely to be necessary), but to illustrate the problem and to put the approximations discussed below in context. Secondly we explain the impact of the CTI pre-processor upon bias files. Thirdly we outline how the pre-processor addresses these issues and finally we contrast the use of standard reference files with and without the CTI pre-processor and CTI corrected reference files with the CTI pre-processor.

2.Derivation of CTI Corrected Dark Files

Dark reference files that are not corrected for CTI are, in fact, more appropriate for use with raw data which is also not corrected for CTI than reference files which are corrected. This is because the uncorrected CTI effects will roughly cancel out. That is, hot pixels will have lost a similar fraction of their charge and have similar CTI trails in the uncorrected raw file and uncorrected reference file (this is an approximation, differing exposure times and illumination pattern surrounding the hot pixels complicate the situation). However, corrected raw data has the hot pixels restored and therefore requires dark reference files that are consistent. Of course astronomers are not interested in having an *accurate* value in a hot or warm pixel and in any case, for dithered observations these values will be taken from the unaffected pixels. Moreover, the low level dark current in most pixels is not significantly affected by CTI which effects the two-dimensional charge distribution when there is a sharp discontinuity, not where there is smooth continuum. However, it is the charge that trails hot pixels that potentially causes problems. This will have been removed from CTI corrected raw data and should therefore be present in dark reference files.

However the derivation of the dark reference files is a complex process. A full description can be found in Landsman 98 and Landsman 97. The processes used at STScI and GSFC differ subtly and have evolved so that the reference file database contains darks derived with slightly different procedures. Moreover, whilst each reference file header contains a list of the datasets it combines, a detailed description of how they were combined is not present. This would make automated re-deriving of existing reference files and simply replacing the data contained in the existing reference files in the OPUS system rather difficult. The alternative would be to compute entirely new reference files and update the science datasets to reference the new dark files also a daunting task.

The basic procedure for deriving the dark reference files can be summarised as follows. Around 10 ~1000s dark exposures are obtained each week and (since July 1998) each ~1000s dark is accompanied by a 60s dark. The deep darks are combined using STIS_CR (cosmic ray rejection). The 60s darks allow the correction of hot pixels which would have saturated in the 1000s dark and also surrounding pixels which would have been affected by blooming. Users may decide themselves whether they want to use the 60s darks, STScI provides the "weekly" baseline darks along with scripts to combine the information from the 60s darks and make "daily" darks which reflect the dark current more precisely on a given day. The monthly annealing of the STIS CCD complicates the situation. This has lead to differing approaches, at GSFC and STScI and at different epochs, for the inclusion of pre and pos-anneal dark exposures in the weekly averaged darks.

For dark reference files created from a simple combination of equal length exposures the CTI correction is not so difficult, we can simply scale to the exposure time of one of the individual exposures and apply our CTI correction code. However the use of the 60s dark exposures undermines this approach. The CTI correction works by simulating the readout of a given charge distribution. The effects for a long exposure (which may include some saturated pixels) will be rather different from those for a short exposure.

For data that is not corrected for CTI we have the following situation. Science exposures of about 60s will have the hot pixels quite accurately removed because the hot pixel in the science exposure will have lost the same fraction of signal as that in the dark (give or take the effect of the differing background). Longer exposures will have the hot pixel over corrected. On the other hand, the trail in the dark will be appropriate for ~1000s exposures and will contain too little charge to correct the 60s science exposure correctly.

So *ideally*, in order to correct the reference files we must reconstruct them from individually CTI corrected dark exposures. Users who wished to use the 60s darks and the CTI pre-processor should be warned that they need to CTI correct these darks as well. Strictly speaking even the standard 1000s darks should each be CTI corrected before being combined to make the baseline dark. The resulting dark reference files would be re-ingested into OPUS and all datasets would have their headers updated to reference the new files. Alternatively, if we want to allow the possibility that users choose not to use the CTI pre-processor then the pre-processor could update the dataset header to reference the CTI corrected dark. Even in this case there would still need to be a database entry that related the datasets to the appropriate CTI corrected dark reference files.

This would then seem to be prohibitively complex. Moreover the simulation code is computationally intensive, re-processing all existing STIS CCD dark reference files would require considerable dedicated CPU time. However, as we show below, the approximation of simply correcting the baseline dark in the pre-processor is in reality very good and makes this unnecessary.

3.How the CTI Pre-Processor handles this Problem

No such CTI corrected dark reference files have been derived, let alone a database populated with them. However the CTI pre-processor pipeline includes an approximate correction to existing dark reference files. This is the simplistic correction that would apply to darks derived from a number of equal length dark exposures.

The pre-processor script first runs the simulation code and derives the correction for a hypothetical dark exposure, based upon the dark file referenced in the header of the dataset scaled to 1100s (the exposure time of most of the long dark exposures). The

corrected dark file is then kept as a temporary file named refdark.fits and the dataset header has the DARKFILE keyword updated to the value "refdark.fits".

The readout simulation obtains some important parameters for the readout it is required to simulate from the headers of the science datasets. However, when used for dark reference files the following setting are always used:

CCDAMP D

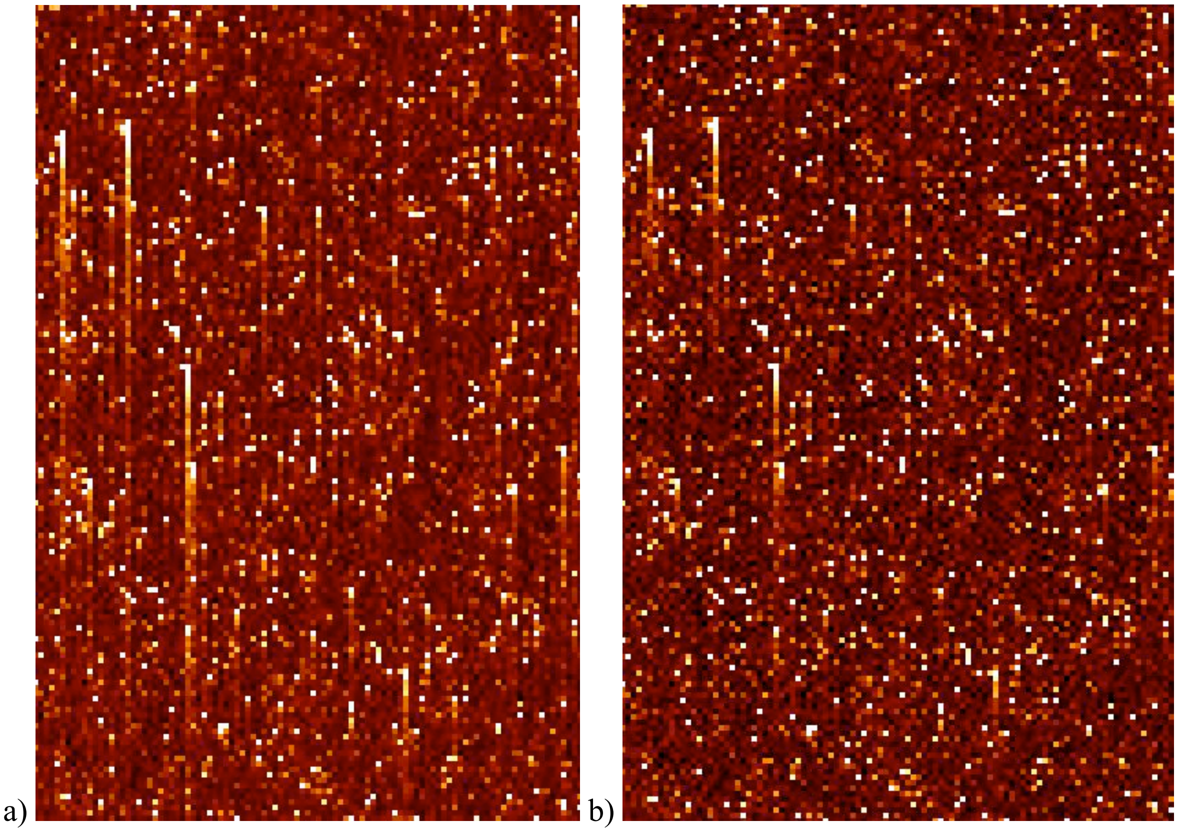
CCDGAIN 1

TEXPTIME 1100

The epoch obtained from the science raw file header (which is used for scaling the trap density in the readout simulation) can safely be applied to the dark reference file, as it must be derived from dark observations of the same epoch.

4. Comparison: Standard pipeline vs. CTI Pre-processor with corrected darks vs. CTI pre-processor without corrected darks

We have outlined above the ideal way in which dark reference files would be re-derived and archived given unlimited resources along with the CTI pre-processor implementation of an approximate correction to the existing dark reference files. We assess the validity of the approximate correction by comparing its performance when applied to CTI corrected raw data with that of the uncorrected dark files applied to raw data without CTI correction. We also show the detrimental effect of using uncorrected dark files with CTI corrected raw data.



- Figure 1: Section of the raw data near to the bottom of the chip. Readout direction is up. a) no CTI correction; b) CTI correction applied

One way to assess the performance of the dark correction is simply to calibrate a dark observation; if the dark correction is good then the result should be a flat image. This is essentially the test that we perform here.

We use the following datasets from calibration proposal 8902

O6HL80BUQ

O6HL88C4Q

O6HL8CQYQ

O6HL89QKQ

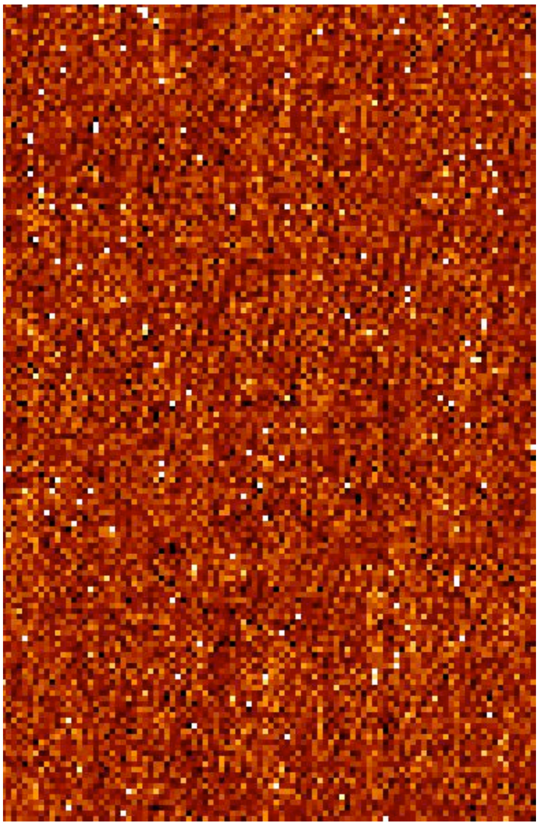
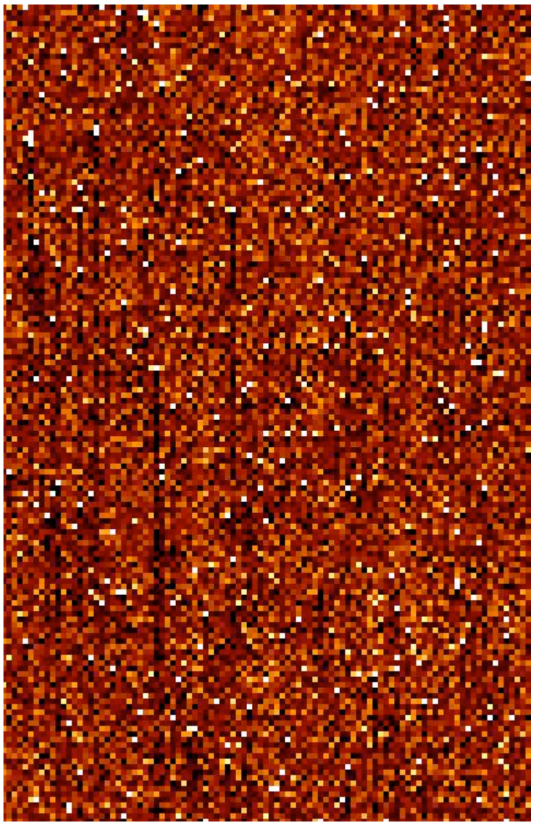
O6HL8TL5Q

We run the pipeline with only the DQICORR and BLEVCORR options. We then combine the calibrated frames with the task occreject to remove cosmic rays. This cosmic ray rejected product is scaled and subtracted from the O6HL80BUQ calibrated frame to reveal its cosmic rays and the result is in turn subtracted from the O6HL80BUQ raw image to arrive at the raw data with just cosmic rays removed.

Now we replace the image extension [1] in o6hl80buq_raw.dat with the cosmic ray rejected raw image (figure 1a) and run this through the pipeline with the DQICORR, BLEVCORR, BIASCORR, DARKCORR, and FLATCORR options. The result is shown in figure 2a. Here we have the data that is not corrected for CTI calibrated for a dark file which is also not corrected for CTI. The result is an extremely flat image; dark current has been removed except for a few anomalous hot pixels. Note that the CTI trails of the hot pixels were also removed.

Next we apply the CTI correction to the raw data (figure 1b) and then calibrated it in the same way. In figure 2b we see that the result is not so flat. Where hot pixels have been removed (to varying degrees of accuracy), underneath there is a dark area. This can be understood by considering the dark image used. Figure 3a is the dark image from the reference file m8e1314lo_drk.fits, clearly visible are CTI trails under the hot pixels. These resemble those in figure 1a and, when the pipeline performs the dark scaling and subtraction, the result is a flat image. On the other hand the CTI corrected raw in figure 1b has already had these trails removed so that the application of the dark causes the erroneous low values below the hot pixels in figure 2b. In the same way, the vale of the hot pixel itself has been corrected in 1b, but this is not reflected in the dark file, so removal of hot pixels is also less accurate.

Finally we consider the use of a CTI corrected dark in the pipeline calibration of CTI corrected raw data. Figure 3b shows m8e1314lo_drk.fits after CTI correction, the CTI trails are no longer visible. Figure 2c is then the result of using this CTI corrected dark in the pipeline calibration of figure 1b. We see that the flat image of figure 2a is more or less recovered.

a)  b) 

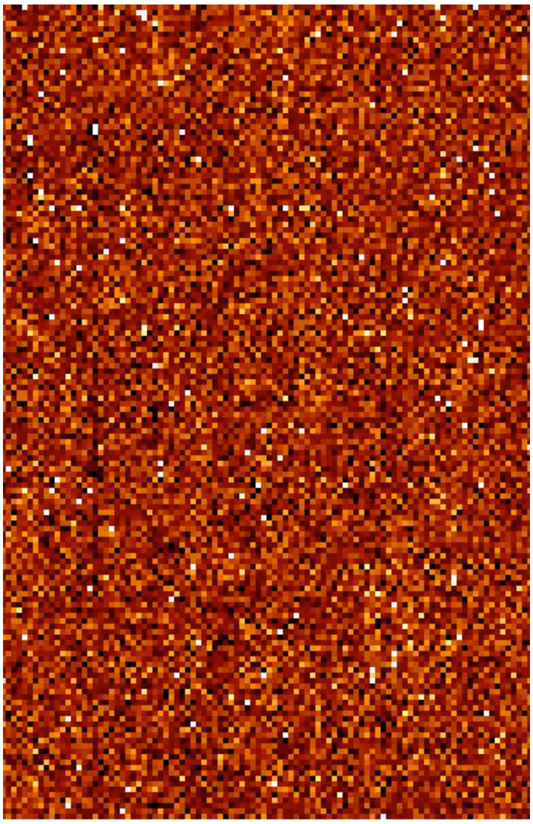
c) 

Figure 2 Section of the calibrated data near to the bottom of the chip. Readout direction is up. a) no CTI correction to raw data or dark reference file; b) CTI correction applied to raw data but *not* to dark reference file; c) CTI correction applied to raw data *and* to dark reference file.

A more quantitative confirmation of this is not straightforward. As we see from figure 2a, there are always some hot pixels that cannot be perfectly corrected with the dark reference file. Such pixels are usually beyond correction in any case (if they are saturated from dark current, or have some spurious behaviour then there is no calibration that can recover the flux which fell on the pixel), the only solution here is dithering. Therefore usually this is a non-issue. However it presents us with a problem when quantifying the flatness of the images in figure 3. Once there is a mismatch between the intensities of hot pixels in the uncorrected (CTI) raw and dark images then this will be magnified by the application of the CTI correction.

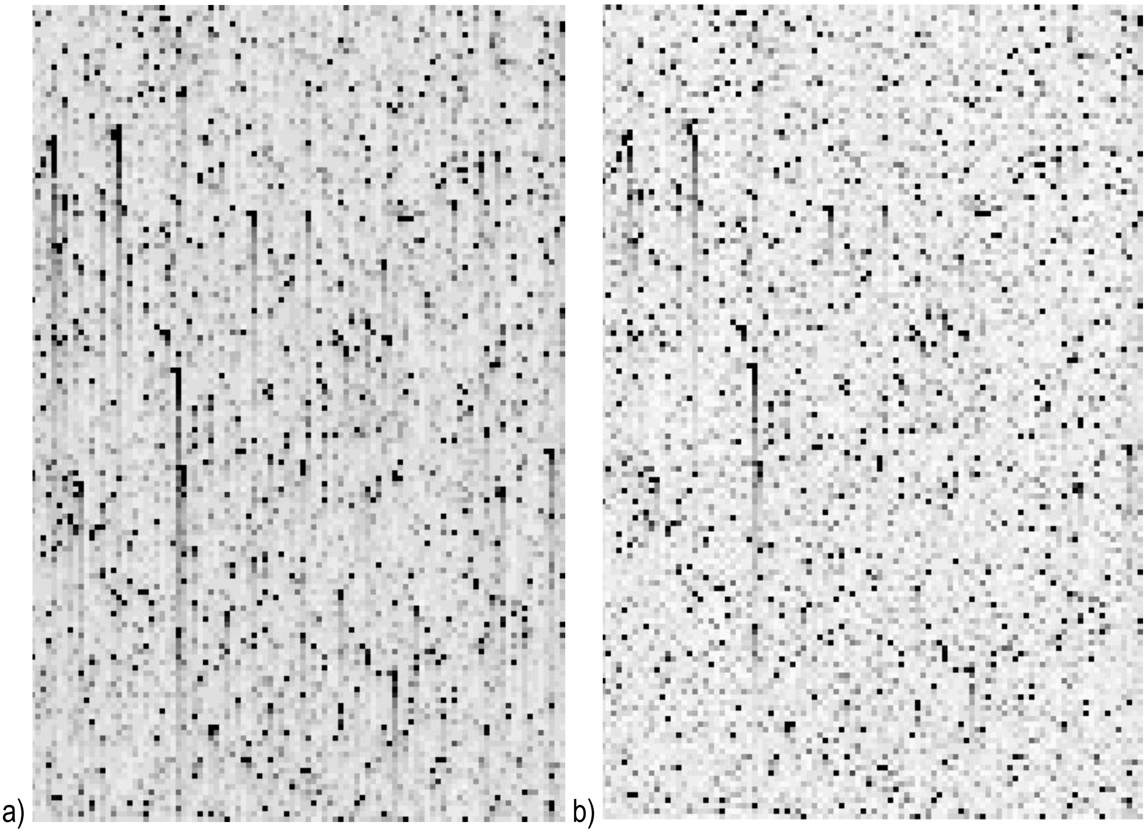


Figure 3: Section of the reference dark image near to the bottom of the chip. Readout direction is up. a) no CTI correction; b) CTI correction applied.

	MEAN	STANDARD DEVIATION
CTI correction to raw, reference dark	-0.4316	5.689
CTI correction to raw and to dark	-0.2754	5.462
No CTI correction, reference dark	0.159	4.774

The mean and standard deviation for figures 3a-c are shown in table 1. The noise introduced in 3b (relative to 3a) by failing to remove the CTI trails in the dark images is clear. It is also clear that this noise is to some extent reduced in 3c by the use of a CTI corrected dark, but perhaps not by as much as we might have hoped, probably for the reasons suggested above.

5. The Effect of the CTI Pre-Processor Upon Bias Reference Files

Strictly speaking, if the CTI pre-processor {\it only} dealt with CTI then there would be no significant effect upon the bias files. However, the CTI correction actually uses a simulation of the readout process. This simulation includes the dark current that "dribbles" into the pixels during charge transfer. This is necessary in order to correctly represent the charge trapping and emission process. Consequently the CTI pre-processor corrects for this charge trailing in addition to CTI. However, this charge trailing is included in standard STIS bias reference files so we must prevent it from being removed twice. Moreover the bias reference files contain further signatures that are not currently dealt with by our CCD readout model, so we cannot simply do without the bias correction step.

The ideal solution here would be to develop the readout model to reproduce all of the information contained in the empirically derived bias files. However, in the absence of such a model we at least want to ensure that the use of the CTI pre-processor does not degrade the good performance of the existing empirical bias files. In order to avoid this we compute the charge dribbling effect that the CTI pre-processor has upon every pixel. We then subtract this from the, reference bias file and store the result in a temporary file refbias.fits. We then update the raw dataset header keyword BIASFILE to take the value "refbias.fits" so that when calstis is run the remaining bias information from the reference bias is applied and the net result, with regards to bias subtraction, is the same as it would have been if the CTI pre-processor had not been used. We emphasize that we are not improving the bias correction in any way here, far from it, we are simply ensuring that the performance of the existing correction is maintained.

6. Conclusions

Dark exposures suffer CTI like any other. However this conveniently cancels out, to a good approximation, with CTI effects upon the signature of the dark in science exposures. However, when science exposures are corrected for CTI with the CTI pre-processor it becomes necessary to correct the dark reference files for CTI.

The ideal solution for this would involve re-derivation and re-archiving of all existing dark reference files. This would likely require an extraordinary effort in order to deal with a relatively minor effect. Instead we have implemented an approximate correction that is applied automatically in the CTI pre-processor. Users wishing to refine the darks they use with additional 60s dark exposures are advised to run the CTI correction first on these exposures before they incorporate them.

Appendix - Note regarding choice of readout amplifier

As described above, the near identical CTI effects upon the dark signature science data and in dark reference files means that data not corrected for CTI will have hot pixel CTI trails removed to a good approximation by application of standard dark reference files. This is however only the case if the science data and the dark exposures were read out in the same direction (essentially through the same amplifier). If this is not the case then CTI correcting both raw and dark would be the only option.

Moreover if a superdark were constructed from dark exposures that were not all read out through the same amplifier then it would be of little use. The only way to correct it would be to CTI correct all component exposures and recombine.

In practise the D amplifier is the only one used for science exposures. All dark exposures to date have also been read out through the D amplifier. The main use of the B amplifier is, in fact, for calibration exposures aimed at measuring the CTI.

The CTI pre-processor assumes that all dark exposures are D amplifier and treats them as such regardless of the science data header. However, B amplifier science data will also be correctly processed, potentially allowing B amplifier science data to be successfully reduced with existing D amplifier darks.

· References

Bristow, P., ISR CE-STIS – 2004 – 001, http://www.stecf.org/poa/pdf/cti_OV.pdf

Landsman, W., IDT STIS post launch ISR 58; http://hires.gsfc.nasa.gov/stis/postcal/quick_reports/r058/r058.html, GSFC 1998

Landsman, W. IDT STIS post launch ISR 31; http://hires.gsfc.nasa.gov/stis/postcal/quick_reports/r031/r031.html, GSFC 1997